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For: CONSISTENT ASSIGNMENT OF UNAMBIGUOUS INDICES TO OBJECTS

Docket: MG-00077

1 **CONSISTENT ASSIGNMENT OF UNAMBIGUOUS INDICES TO OBJECTS**

2 Cross-reference to Related Applications

3 This application is related to copending patent application [Docket No. MG-00067]
4 filed concurrently herewith.

5 Government Rights in the Invention

6 The United States Government has rights in this invention pursuant to Contract No.
7 F04701-96-C-0044 with the Department of the Air Force.

8 Background of the Invention

9 1. Field of the Invention

10 The invention relates to the assignment of unique identifiers or indices to a plurality
11 of objects in an n-dimensional space. Particularly, it relates to an assignment schema that
12 assigns the identifiers or indices unambiguously in a consistent manner, especially where
13 there are a plurality of successive assignments of indices to variations in the pattern of
14 the objects, e.g., in successive time-separated observations.

15 2. Background

16 A common problem in multiple target tracking is the identification of individual
17 targets in a cluster of targets. This is particularly true when the cluster is not observed
18 continuously. In scanning or staring sensors, the cluster is observed momentarily. The
19 time interval between observations may be long and the motion of clusters is fast enough
20 that the error in prediction of the target's positions is greater than the separation of the
21 targets in the cluster.

1 It is often necessary to assign indices to objects so that all the observations are in the
2 K same relative order as closely as possible. Furthermore, if additional noise or
3 background observations are added or some of the objects do not appear during
4 successive observations, the relative order must still be maintained to the maximum
5 extent possible. By relative order is meant that if an object o_i is indexed ahead of object
6 o_j in one cluster, object o_i will likely be indexed ahead of o_j in subsequent clusters.

7 Applications of the invention include object identification in aerial surveys and
8 sorting multiple targets as in a ground-controlled radar approach system.

9 Brief Summary of the Invention

10 In accordance with the invention, a method of assigning identifying indicia to objects
11 in a multidimensional space includes arranging the objects initially according to a first
12 dimension of their location in the multidimensional space and grouping subsets of
13 objects according to any ambiguities in the arrangement. Unsorted objects, i.e., having no
14 index assigned, are ordered in subsets according to other dimensions of the
15 multidimensional space. The first dimension is preferably that along which separation of
16 objects exhibits the greatest dispersion. If the coordinate in the dimension is substantially
17 equal to that of another object, no index is assigned to one of them according to one of
18 several approaches. The process is complete when all objects have been assigned an
19 index.

20 Brief Description of the Figures of the Drawing

21 The invention is described in detail by referring to the various figures of the drawing

1 which illustrate specific embodiments of the invention, and wherein like numerals refer
2 to like elements.

3 FIG. 1 is an illustration of seven points showing the general problem solved by the
4 invention.

5 FIG. 2 is a flowchart of a preliminary part of the implementation of the invention.

6 FIG. 3 is a flowchart of an ASSIGN subroutine embodying the invention.

7 Detailed Description of the Invention

8 One of the difficult problems in tracking closely spaced objects is to correlate
9 observed objects with tracks. A track is defined as a collection of all observations of a
10 single object. A pattern sorting algorithm is disclosed to order all the observations for
11 each of several observations (snapshots) of all the objects in a consistent manner. Also,
12 for purposes of explanation, the coordinate directions (dimensions) are written in upper
13 case, e.g., as X1 and X2, and the measurements along the axes in lower case as x_1 and x_2 .
14 The points are denoted as P_n or $P_n(x_1, x_2, \dots, x_m)$ where m is the number of dimensions
15 involved and x_i is the value of the i -th coordinate in dimension X_i . The index assigned to
16 point P_j is denoted by $\#P_j$.

17 The invention will be explained using an example of the problem which the
18 invention is directed to solving, viz., the consistent assignment of unambiguous indices
19 to a plurality of points in a multidimensional space. An illustrative example is shown in
20 FIG. 1 which depicts seven points in a three-dimensional space. The axes are X1, X2,
21 and X3. (These are commonly referred to as the x-, y-, and z-axes but the more

1 generalized reference will be used for consistency since there are situations where more
2 than three dimensions may be required.)

3 Sensing devices have known error distributions. For example, in a passive sensor
4 array comprising a plurality of elements, a known error of measurement is associated in
5 both the horizontal and vertical directions. Therefore, each dimension is assigned a
6 threshold value. Where the objects are maneuvering targets, two thresholds may be
7 assigned. The first could be a jitter threshold based on the measurement errors of the
8 system. These errors are known to the user and vary widely depending on the sensors and
9 processors used in a particular sensor. A threshold of $3.5\sigma_e$, i.e., related to the standard
10 deviation of the measurement error, should sort the points correctly 99.7-percent of the
11 time. For purposes of illustration in the following example, the thresholds are taken as
12 zero. In practice, the thresholds would be determined depending on the nature of the
13 system.

14 The second threshold can be derived from the motion of the objects from one
15 observation to another. The two thresholds can be combined into a single threshold in a
16 statistical manner.

17 The points can be initially numbered in any convenient order, in this case from the
18 top toward the bottom, i.e., in descending order along the z-axis. The points located in
19 the three-dimensional space of FIG. 1 are: P0(2,1,8), P1(1,1,5), P2(2,1,5), P3(3,1,5),
20 P4(2,3,5), P5(2,1,2), and P6(1,1,2). If the points are sorted (and assigned indices) along
21 the X1 axis, the points P0, P2, P4, and P5 would be ambiguous as would points P1 and

1 P6 since both sets have the same x_1 value. Similarly, sorting along the X2 axis creates an
2 ambiguity among the points P0, P1, P2, P3, P5, and P6 since all have an x_2 value of 1.
3 Along the X3 axis, the points P1, P2, P3, and P4 have the same x_3 value as do points P5
4 and P6.

5 In situations such as described in copending patent application [Docket No.
6 MG-00067], it is essential to assign indices in a consistent manner so as to correlate
7 points from one varying pattern to another. Although some points may change position
8 from one pattern to another, e.g., in time-varying observations, a consistent system of
9 index assignment aids the correlation of points using the technique disclosed in
10 copending patent application [Docket No. MG-00067].

11 The technique to be described in detail is preferably practiced by sorting the points
12 along the various dimensions in the order according to their distribution in descending
13 order of their dispersion. That is, the first dimension in the sort order is the dimension
14 exhibiting the largest dispersion. Various measures of dispersion are available. The one
15 used here is the standard deviation (σ) which is usually the most efficient and indicative
16 of the distribution spread of variables. The second threshold could be a motion threshold
17 and taken as the maximum relative speed of one target with respect to any other target.

18 In the following description, references are made to the flowcharts depicting the
19 sequence of operations performed by the program. The symbols used are standard
20 flowchart symbols accepted by the American National Standards Institute and the
21 International Standards Organization. In the explanation, an operation may be described

1 as being performed by a particular block in the flowchart. This is to be interpreted as
2 meaning that the operations referred to are performed by programming and executing a K
3 sequence of instructions that produces the result said to be performed by the described
4 block. The actual instructions used depend on the particular system used to implement
5 the invention. Different processors have different instruction sets but persons of ordinary
6 skill in the art are familiar with the instruction sets with which they work and can
7 implement the operations set forth in the blocks of the flowchart.

8 The preliminary procedures for sorting (and assigning indices to) the points are to set
9 up the data, i.e., the points, and to determine the order of sorting and threshold values for
10 each dimension. The assignment of indices is then performed. A pseudo-code listing
11 below shows the basic steps. The total number of points is n and the number of
12 dimensions is m . In the illustrative example, $n = 7$ and $m = 3$ and the procedure is
13 recursive.

14 Setup array of points with #P=0

15 Calculate statistics for each dimension and set J sort order

16 Set up threshold values for each dimension T_j

17 Index = 1

18 Call ASSIGN

19 Subroutine ASSIGN

20 If no open points

21 Return

22 Sort J-array

23 Set $i = 0$

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1  —Loop:
2  Move P[i] to J+1-array
3  k = 1
4  While  $|x[i,j] - x[i+1,j]| < T_j$ 
5      Move P[i+1] to J+1-array
6      i = i + 1
7      k = k + 1
8  If k = 1
9      Assign Index to P[k,j+1]
10     i + 1
11 Else
12     If J = m
13         Force Assignment
14         Go to EndTest
15     Else
16         J = next J
17         Call ASSIGN
18         J = previous J
19 —EndTest:
20     If i > k
21         Return
22     Else
23         Go to Loop

```

24 A flowchart for the preliminary steps in practicing the invention is set forth in FIG.

25 2. The process begins when it is entered via a terminal block 201. First, in a process
26 block 202, the data array is setup. This is a table, list, or other collection of the objects

1 together with their parameters including the coordinate values along the applicable
2 dimensions. The index value for each point is initially set to zero. This provides a basis
3 for determining which points remain to be processed. For example, the index of each
4 point can be sensed and if none are zero, the assignment is completed.

5 The successive values of J are the dimensions on which the successive sort criteria
6 are based. The order of sorting for the present J-array is determined at a process block
7 203. The order of the dimensions in which the points are to be processed are determined
8 from the statistics of the spread of the objects' locations along each dimension. The order
9 of processing the dimensions should be along those which exhibit the greater dispersion,
10 e.g., having the larger standard deviations among the points.

11 The threshold values for each dimension are set up in an array in a process block
12 205. The index value is then initialized to 1 in a process block 206. A subroutine
13 ASSIGN is called as shown in block 207. When the program has completed execution of
14 the ASSIGN subroutine, the process is exited via a terminal 209.

15 FIG. 3 is a flowchart for the ASSIGN subroutine. It starts at a terminal 300 when
16 called by the main program. The subroutine first checks, in a decision block 301, whether
17 there are any open points, i.e., whether there are points that have not been assigned an
18 index. One approach is to ascertain whether the value of the index is greater than n, the
19 total number of points. Another approach is to determine whether any point's index
20 remains an initially assigned value of zero.

21 The J-array is then sorted in a process block 303. Once the J-array is in the order

1 according to the dimension J, a list pointer I is set to 0, the point P[I] is moved to a
2 J+1-array, and a count K is set to 1. The K count is the number of points which have
3 been moved into the J+1-array.

4 Next, the J-th coordinate of the point P[I+1] is compared to the J-th coordinate of the
5 point P[I]. If the magnitude (absolute value) of the difference between them is less than
6 the J-th threshold, T[J], as determined in a decision block 304, then the point P[I+1] is
7 moved into the J+1-array and the values of I and K are incremented in a process block
8 306. When the magnitudes of difference between successive points is not less than the
9 threshold, the value of K is tested by a decision block 307. If K = 1, only one point has
10 been moved to the J+1-array and therefore no ambiguity exists with respect to other
11 points. The present value of the index is assigned to the point and the index value is
12 incremented as denoted by (+1) in a process block 308. The value of I is incremented in a
13 block 316 and the process continues by moving the next P[I] to the J+1-array.

14 If, at the decision block 307, K is not equal to 1, then the J+1-array contains K points
15 having the same x_j value, i.e., are ambiguous. A check is made at a decision block 309 to
16 determine whether all the dimensions have been processed. If so, then at a process block
17 310, the assignment of the indices of the points in the array is forced. One forced
18 assignment method is to allocate the indices in the order in which the points appear in the
19 array.

20 At a decision block 314, the value of I is compared to K to ascertain whether all the
21 points in the J-array have been processed. If so, the return at a terminal block 315 is

1 executed. If not, the process continues at the block 303 and proceeds as described above.

2 If additional dimensions are to be processed, then at a process block 311, J is
3 replaced by the next dimension. The subroutine block 312 indicates that the subroutine
4 ASSIGN is called. Calling a subroutine from within the subroutine itself is termed
5 reentrant and permits recursive processing. Recursive processing can be converted to
6 reiterative processing using known techniques. For example, the call to the subroutine is
7 replaced by pushing the local variables and return addresses onto a stack, pushing the
8 present address onto the stack, and branching to the beginning of the subroutine. The
9 return in the recursive version is replaced by executing a normal return if the stack is
10 empty or, if the stack is not empty, popping the return address from the top of the stack,
11 popping all the local variables and parameters and assigning them to their corresponding
12 variables and parameters, and then branching to the popped return address. Alternatively,
13 pointers to the variables, i.e., their memory location addresses, can be pushed onto and
14 popped from a stack.

15 When all the points in the array being processed have been indexed, J is replaced by
16 the previous value in a process block 313 and the test for the J-array (where J is now the
17 previous J when the subroutine was reentered) is made to determine whether it contains
18 any unprocessed points. In reentrant programs, the local variables (such as I and K in this
19 case) are not the same in each of the re-entries into the subroutines being recursively
20 processed unless assigned globally. Also, the return from the terminal 313 is to the
21 calling program, in this case to the process block 313 if the subroutine were called from

1 within the subroutine.

2 In one implementation, the first of a group of ambiguous points can be assigned the
3 current index value and the remaining ambiguous points of the groups gathered into an
4 array, sorted according to the next dimension, and assigned indices accordingly. It is
5 possible, however, that the next time the pattern is processed, the input order may have
6 changed. This would result in a different first point of an ambiguous group being
7 assigned the next index value which would create a less consistent assignment. By
8 recursively processing the arrays of ambiguous points, the points are indexed most
9 consistently.

10 The exemplary points of FIG. 1 will now be processed in accordance with the
11 invention. The original ($J = 0$) array is, where the number in square brackets is the point's
12 index and the x_1 , x_2 , and x_3 coordinates are in parentheses:

13 PO[0](2,1,8)

14 P1[0](1,1,5)

15 P2[0](2,1,5)

16 P3[0](3,1,5)

17 P4[0](2,3,5)

18 P5[0](2,1,2)

19 P6[0](1,1,2)

20 The statistics (mean and standard deviation) of the points:

21 $\mu_1 = 1.857$; $\mu_2 = 1.286$; $\mu_3 = 4.572$;

22 $\sigma_1 = 0.690$; $\sigma_2 = 0.756$; $\sigma_3 = 2.070$.

1 Therefore, the J-values are in the sequence 3, 2, and 1. The first sort is along the X3 axis
2 followed by the X2 and X1 axes. As shown above, the original array, now the 3-array, is
3 already sorted in descending order by x_3 since the preliminary assignment of point
4 identifiers was arbitrarily made along the X3 axis from the top down.

5 The point P0 is moved to the 2-array and K is set to 1. Since $|x_{3,0} - x_{3,1}| > 0$, the point
6 PO is assigned the index 1 and the index value is incremented to 2. The 3-array is now:

7 P0[1](2,1,8)
8 P1[0](1,1,5)
9 P2[0](2,1,5)
10 P3[0](3,1,5)
11 P4[0](2,3,5)
12 P5[0](2,1,2)
13 P6[0](1,1,2).

14 The point P1 is now moved to a new 2-array and K is set to 1. Since $|x_{3,1} - x_{3,2}| = 0$, the
15 point P2 is moved to the 2-array. Similarly, points P3 and P4 are moved to the 2-array.

16 The 2-array is:

17 P1[0](1,1,5)
18 P2[0](2,1,5)
19 P3[0](3,1,5)
20 P4[0](2,3,5)

21 Since K is greater than I and all the dimensions have not been processed, the
22 subroutine ASSIGN is called. The 2-array is sorted to

23 P4[0](2,3,5)

1 P1[0](1,1,5)

2 P2[0](2,1,5)

3 P3[0](3,1,5).

4 The point P4 is moved to the 1-array (since X1 is the next array in the sort order
5 according to the statistics of the 2-array). The value of K is set to 1. The magnitude of the
6 difference between $x_{4,1}$ and $x_{4,2}$ is greater than 0 so the point P4 is assigned an index of 2
7 and the index value is incremented to 3.

8 The point P1 is then moved to the now-empty 1-array and K set to 1. Since the
9 magnitudes of the differences between the next pairs of the $x_{i,2}$ values are 0, the points P2
10 and P3 are also moved to the 1-array and sorted. The order of the points in the 1-array is
11 P3, P4, and P1. Since the magnitudes of the differences along the X1 axis are greater than
12 zero, they will each be assigned an index. The assignments of indices are made in the
13 order of the sort so that P3 is assigned the index 3, the point P2 is assigned the index 4,
14 and the point P1 is assigned the index 5. The index value now has the value of 6 from the
15 successive increments.

16 Next, the return from the subroutine is executed. Since it was called from within the
17 subroutine itself, the return next drops back to the previous J-array, that is, the 3-array.

18 Because of the mesne assignments, the 3-array is now:

19 PO[1](2,1,8)

20 P1[5](1,1,5)

21 P2[4](2,1,5)

1 P3[3](3,1,5)

2 P4[2](2,3,5)

3 P5[0](2,1,2)

4 P6[0](1,1,2).

5 The point P5 is moved to the 2-array and so is P6 since the magnitudes of the
6 differences between the x_3 values are zero. The statistics indicate that the 2-array should
7 be sorted along the X_1 axes. Since the x_1 values are different, the points are assigned the
8 indices 6 for P5 and 7 for P6. The final result is:

9 PO[1](2,1,8)

10 P1[5](1,1,5)

11 P2[4](2,1,5)

12 P3[3](3,1,5)

13 P4[2](2,3,5)

14 P5[6](2,1,2)

15 P6[7](1,1,2).

16 While the invention has been particularly shown and described with reference to a
17 preferred embodiment thereof it will be understood by those skilled in the art that various
18 changes and modifications in form and details may be made therein without departing
19 from the spirit and scope of the invention according to the following claims.